Advantages of Vehicle Fuel vs Other Biogas Uses in Agricultural AD Systems

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American biogas Council

www.americanbiogascouncil.org

Raw Biogas Characteristics

- Pressure:
  - Common: 2 – 8 inches of water column
  - Municipal applications: up to 15 inches

- Major Constituents:

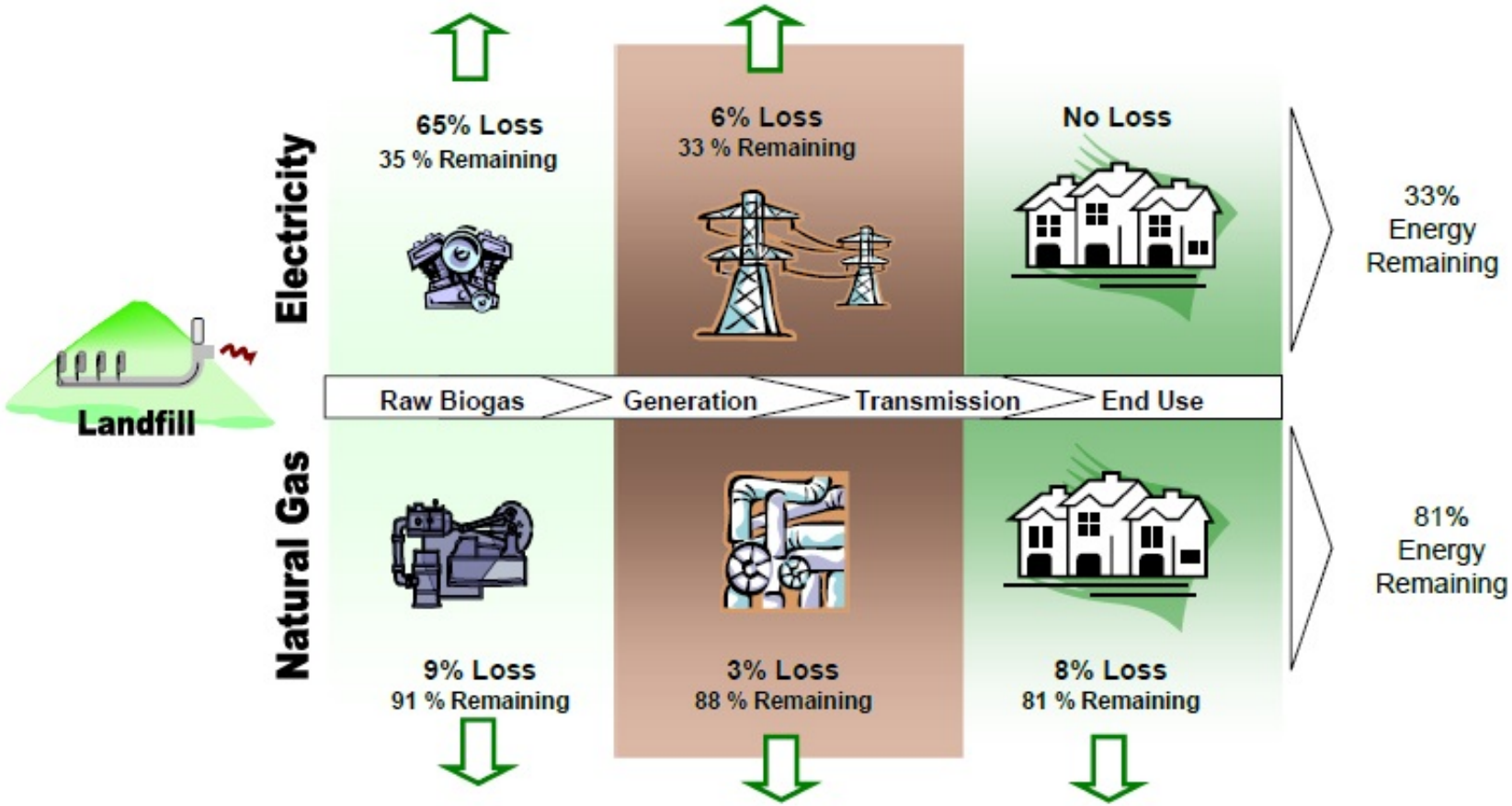
Constituent	Concentration
Methane (CH_4)	55-60%
Carbon Dioxide (CO_2)	40-45%
Nitrogen (N_2)	0.4-1.2%
Oxygen (O_2)	0.0-0.4%
Hydrogen Sulfide (H_2S)	0.02-0.4%
Water (H_2O)	Saturated

Biogas Use Options

- Heat Only: ~92% Heat Recovery Efficiency
- Power Only: ~38% Electrical Efficiency
- Renewable Natural Gas: ~99% Energy Available to Pipeline
- Combined Heat and Power (CHP): ~65% Electrical and Heat Recovery Efficiency
- CNG Vehicle Fuel: ~99% Energy Available to Vehicle

Increasing Capital Costs

Vehicle Fuel vs Other Uses



Biogas Vehicle Fuel vs Other Uses

- Other factors to consider for biogas upgrading projects to CNG are:
  - Diesel and gasoline powered vehicles are more costly to operate and maintain than CNG vehicles
  - Biogas to CNG is a proven technology. CNG vehicles running on biogas derived CNG have been running for over a decade
  - Farms vehicles such as utility vehicles, milk trucks, and pick-up trucks for essential farm operations can be converted or purchased to operate on locally produced CNG
  - In areas with low electricity feed-in prices and / or high network connection costs, biogas to electricity projects are not viable. Upgrading biogas to vehicle fuel can make digester projects economically viable again.

Biogas to Vehicle Fuel Examples

Greenlane® Totara+
Fair Oaks, Indiana

Greenlane® **Rimu**
Hamilton, Ontario

Greenlane® Manuka
Motala, Sweden

Greenlane® 2 x Totara
Madrid, Spain

Financial Considerations

Fuel Comparison

Distance Travelled on $10 of Fuel (assuming 25 MPG)

- At $4 per gallon of diesel (2.5 gal) = 63 miles
- At $3.50 per gallon of gasoline (2.8 gal) = 71 miles
- At $5 per MMBTU of Natural Gas (at $0.65 per GGE)* = (7.7 GGE) = 192 miles

*$/Gal of gas equivalent

$$\text{GGE} = (\$5/MMBTU) \times (0.13\ MMBTU/Gal)$$

Perform Feasibility

- Operational costs associated with converting to RNG vehicle fuel need to be considered:
  - Vehicle Conversions or New Vehicles
  - Digester Heating and Operational Costs
  - Biogas Upgrading Costs
  - CNG Compression and Dispensing Costs
  - Utility Costs
  - Labor
  - Etc.
- Capital costs, financial costs, and development & permitting expenses need to be well understood, along with applicable grants and incentives.
- RNG storage costs must also be considered due to vehicle fueling cycles. A connection a natural gas pipeline is often optimal.

Sensitivity Analysis

- Most important variables for biogas upgrading projects to CNG are:

Substitute Fuel Prices (Diesel & Gasoline)

- Higher diesel and gasoline prices (including tax) relatively improve the project IRR.

High Biogas Utilization

- For biogas production, biogas upgrading, CNG compression and dispensing, operational reliability and quality are key. Ensuring RNG production is maximized also important, by ensuring CH4 yield and system availability is high. A natural gas pipeline 'bank' for RNG storage is recommended.

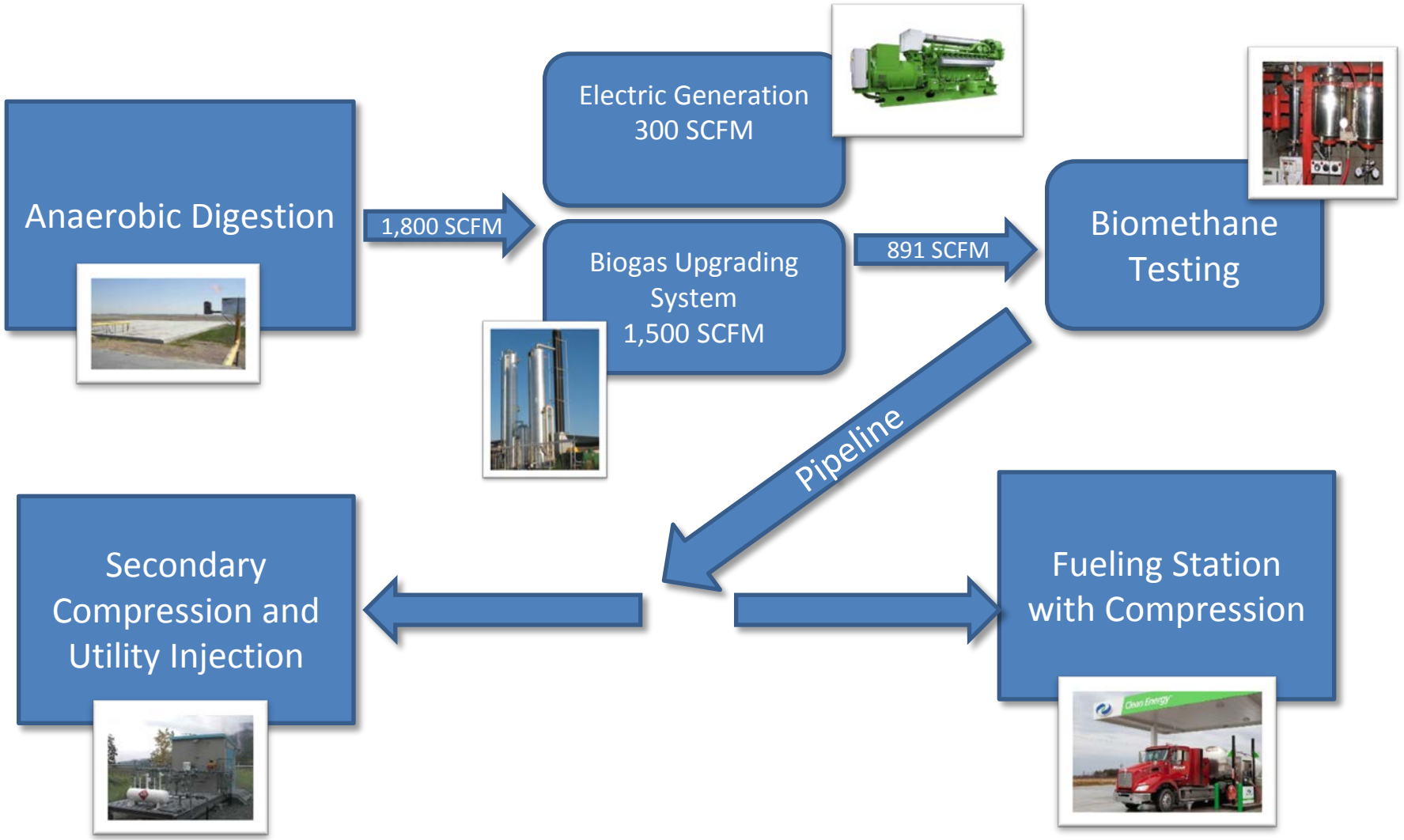
Capital and Operating Costs

- Important, but often not as important as the two points above. CAPEX and OPEX need to be optimized for the project's scale and local requirements.

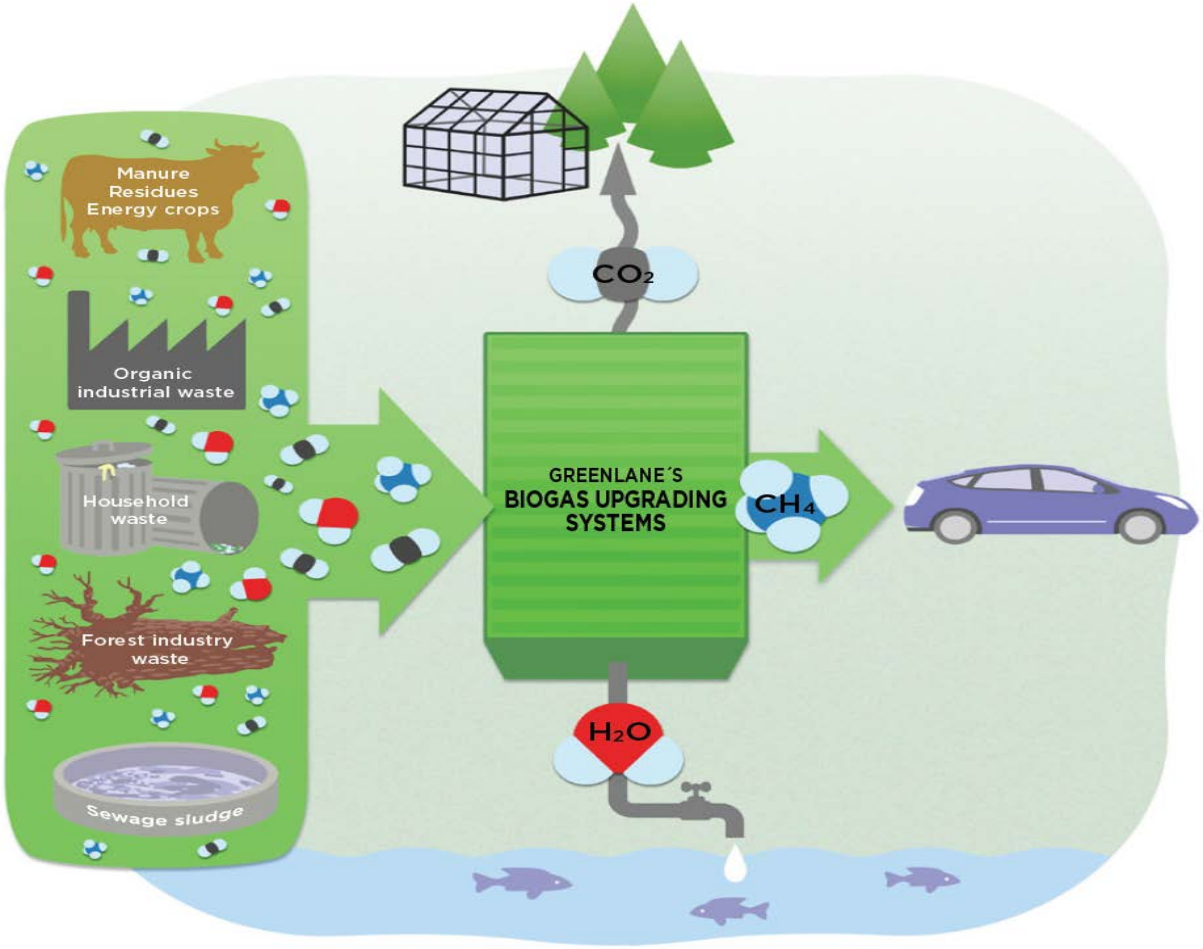
Financing Costs

- Debt vs. equity, interest rates associated, tax credits and other governmental supports, often determine if the project will proceed or stall.

Fair Oaks –Process Overview



Technical Considerations



BIOGAS requires upgrading to be used as CNG or LNG Vehicle Fuel

Renewable Natural Gas Interchangeability

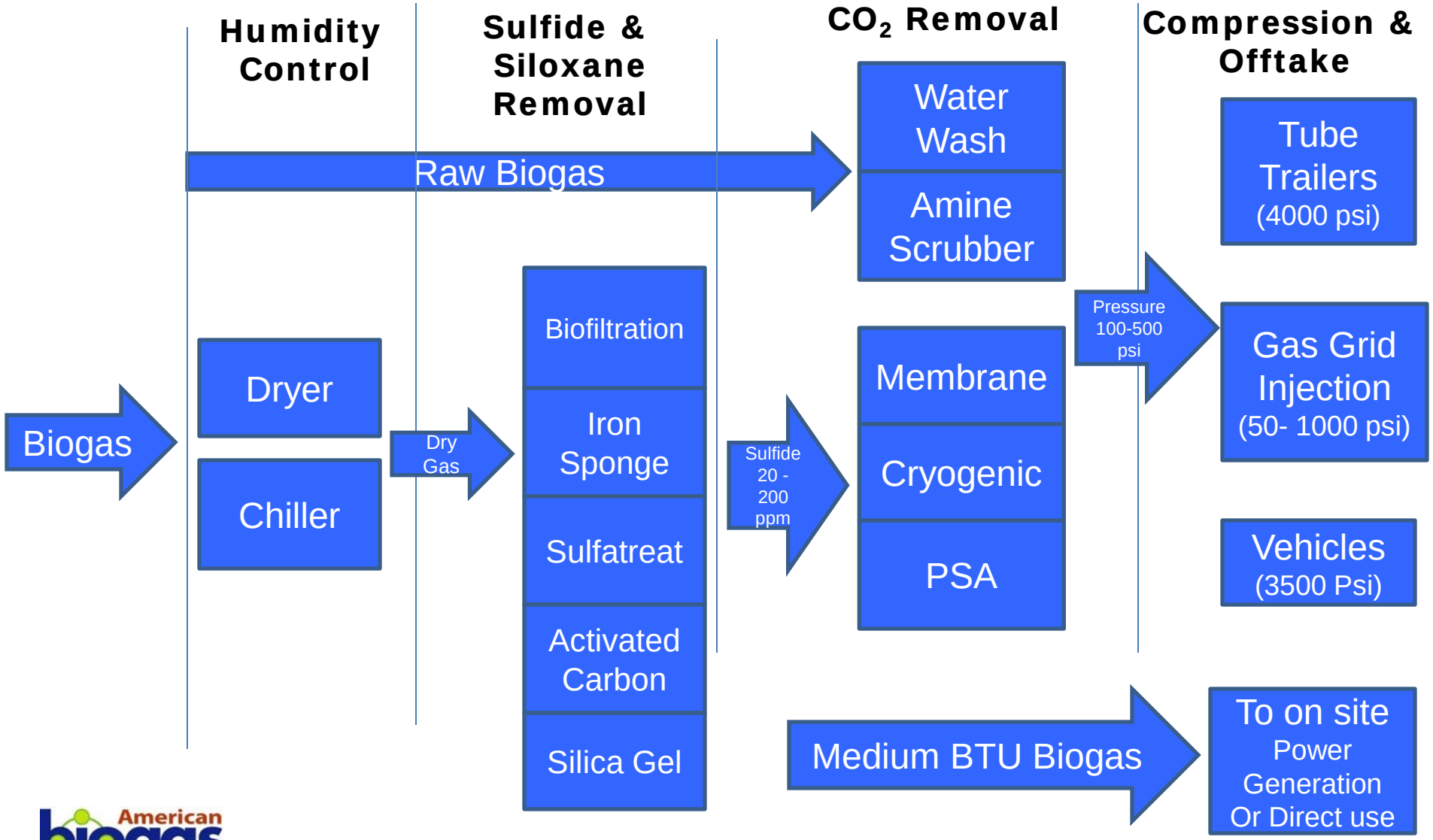
- Upgraded biogas can be interchangeable with natural gas

Selected standard requirements for grid injection or for utilization as vehicle fuel.

Compound	Units	Reported Tariff Range
Heating Value	Btu/scf	950 - 1000 (min) 1075 - 1200 (max)
Carbon Dioxide	% volume	1 - 3
Nitrogen	% volume	1 - 4
Oxygen	% volume	0.001 - 1
Hydrogen Sulfide	grains of H2S/100scf	0.25 - 1
Water Content	lb/MMscf	4 - 7

Source: AGA Report No. 4A - Natural Gas Contract Measurement and Quality Clauses (DRAFT update, 2009)

Upgrading Steps



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Technology Comparison

Process	Benefits	Disadvantages
Physical Solvent (other than water)	1. High absorption rate 2. High CH4 yields possible 3. Can deliver biomethane at low pressure	1. Safety – solvent is dangerous to handle 2. Complex process – difficult control system 3. Prohibitive capital costs for new equipment 4. Biogas / LFG contaminants cause foaming
Physical Membrane (high pressure process)	1. Low capital cost 2. Simple plant 3. Experience upgrading LFG	1. Low biomethane purity 2. High energy consumption 3. Membranes foul and require replacement
PSA / VSA (pressure swing adsorption or molecular sieve)	1. Can remove some inert gases, often with an additional process module 2. Low efficiency version cost effective on small scale	1. Media becomes fouled and needs replacement 2. Process difficult to control – problems maintaining high CH_4 recovery 3. Bed fluidization causes “dusting” of media 4. Upstream H_2S removal required
Water Scrubbing (with PSA/TSA purifier)	1. Excellent safety; proven performance 2. Reliable, simple and easy to maintain 3. Low capital and operating costs 4. Siloxanes effectively removed	1. Practical capacity limit of ~1500 scfm 2. Does not remove inerts (e.g. O_2 and N_2)

Biogas Upgrading via Water Scrubbing

A Simple Concept

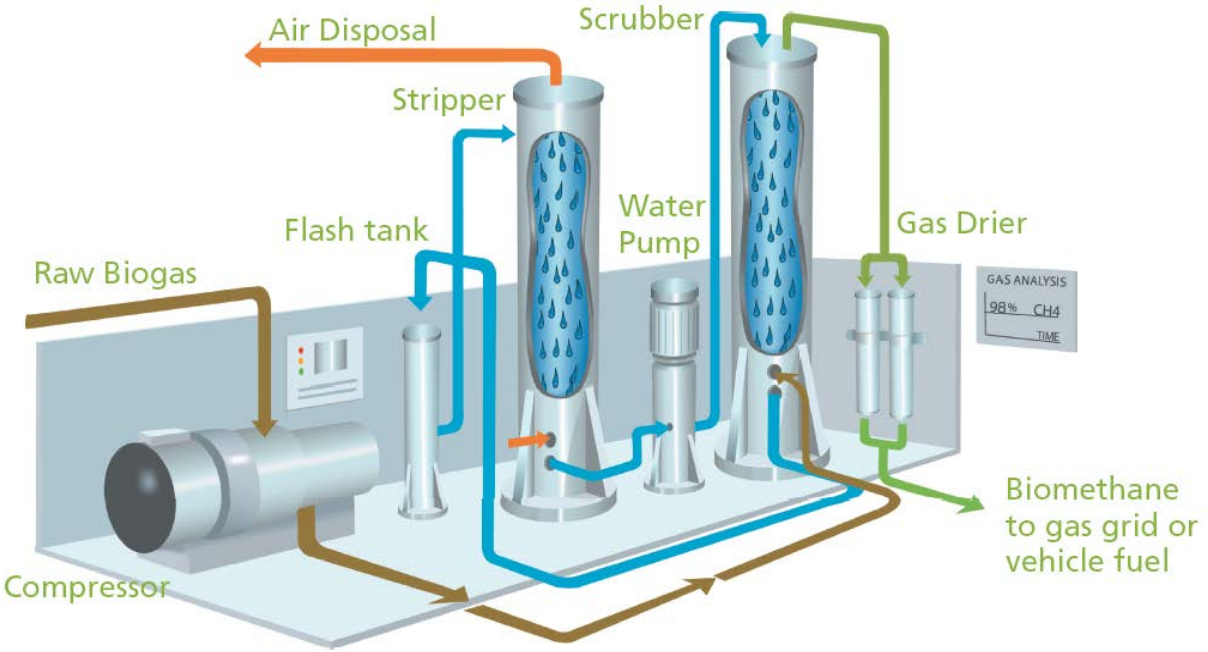
- Biogas is primarily methane (CH_4) and carbon dioxide (CO_2)
- Water under pressure can be used to separate these two gases through their different solubility in H_2O

Water Regeneration

- Water from the scrubber is sent to flash tank to depressurize, so the small amount of absorbed methane can be removed from the water
- The water is then sent to a stripper that removes the gases absorbed in the water
- The water can now be reused to clean biogas

How Water Scrubbing Works

- The raw biogas is compressed, then fed to a ‘scrubbing’ vessel where it is contacted with water. CO2, H2S, siloxanes and other trace contaminants are preferentially absorbed by the water
- Absorbed methane is ‘flashed’ off, in a vessel at a lower pressure and recovered by returning it to the start of the process
- Product gas is further purified by a proprietary TSA, before being analyzed and delivered



Greenlane Technology in Focus

- Water used upgrade the biogas – A simple, safe and efficient process efficiently upgrades raw biogas to vehicle fuel or pipeline standards

- Hydrogen Sulphide - Greenlane's innovative, patented "polishing" process is proven to reduce biomethane H2S carryover to less than 1 ppm in the biomethane

- Siloxanes - Greenlane's system removes siloxanes to the levels required for reliable use for engines (sub-ppm)

- Track Record - Greenlane has the longest track record in the industry

Our Company

Greenlane

- Greenlane began as Flotech, which was founded 1986 in New Zealand to provide machinery installation services to the compressed natural gas industry.

- Greenlane is the global leader in the biogas upgrading market, with ~70 installations in 15 countries. The company uses a water scrubbing and pressure / temperature adsorption gas cleaning process to produce renewable natural gas (RNG) from biogas and landfill gas.

- The organization operates internationally, offering solutions for:

  - Gas Purification, Drying and Conditioning
  - Industrial Heat Exchange
  - Gas Compression
  - Technical Support, Field Services and Spare Parts

Thank You for Your Attention!

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